

**Biomass and Population Structure
of Kelp (*Laminaria* spp.) in
Southwestern Nova Scotia**

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IN SOUTHWESTERN NOVA SCOTIA

by

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ABSTRACT

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A survey using a combination of aerial photography (1:10,000 colour) and groundtruthing on diving transects located 577 ha of mixed kelp species. Aerial photography was most effective where kelp was less than 4 m deep and where the edge of kelp beds was outlined by a substrate transition. Sixty-three percent of the area occupied by kelp was located by aerial photography. Average biomass density was 42.2 t ha⁻¹, comprising 40% Laminaria digitata and 60% Laminaria longicruris. The predominantly boulder substrate supported 23,376 t fresh weight of kelp. The majority of biomass was located between 0 and 5 m water depth along semi-exposed and exposed shorelines. In the most wave-exposed locations, L. digitata was the dominant species, whereas it was 30% or less of the total biomass in sheltered areas. The population structure of kelp species varied with depth, substrate, water movement, and wave exposure. However, with the exception of wave exposure, plant morphology did not vary significantly along environmental gradients.

RÉSUMÉ

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Une étude utilisant une combinaison de photographie aérienne (1:10,000 couleur) et de vérification de terrain sur des transects de plongée a défini 577 hectares d'espèces mixtes de laminaires. La photographie aérienne était plus efficace aux profondeurs de moins de 4 mètres où le bord de la distribution des laminaires était délimité par une transition du substrat. Soixante-trois pourcent de la superficie défini a été repéré par la photographie aérienne. La densité moyenne de la biomasse était 42.2 tonnes hectares⁻¹, comprenant 40% Laminaria digitata et 60% Laminaria longicruris. Le substrat prédominant de grosses pierres supportait 23,376 tonnes de poids frais de laminaires. La majorité de la biomasse était situé entre 0 et 5 m de profondeur d'eau le long des côtes semi-exposé et exposé. Aux locations les plus exposées aux vagues, L. digitata était l'espèce dominante alors qu'elle était 30% ou moins de la biomasse totale dans les endroits protégés. La structure de la population des espèces de laminaires varie avec la profondeur, le substrat, le mouvement de l'eau et l'exposition aux vagues. Cependant, avec l'exception de l'exposition aux vagues, la morphologie des plantes ne varie pas de façon significative le long des gradients environnementaux.

1.0 INTRODUCTION

From 1942 to 1949, kelp (Laminaria) was harvested in southwestern Nova Scotia, reaching a maximum of 3,000 tonnes per year (Sharp 1980). The final product was sodium alginate, an emulsifier and gelling agent.

Commercial uses of kelp range from fertilizer to a direct human food stuff (Chapman 1970). The value of macrophyte stands as a habitat for invertebrates has been recognized (Pringle et al. 1980). The contribution of Laminaria to coastal primary productivity is also well documented (Mann and Breen 1972; Field et al. 1977).

Following the early harvest of kelp in southwestern Nova Scotia, the macrophyte beds of the area were surveyed between 1948 and 1950 (MacFarlane 1952). A portion of the area covered by ground surveys was the subject of an experimental air photo survey (Cameron 1950). Although standing crop estimates were given, no maps were published and the air photos are not available. A diving survey of deep (>6 m) Chondrus beds incidentally identified some Laminaria beds (Haggarty and Hillenbrand 1976).

Re-survey of six Laminaria beds identified by MacFarlane (1952) suggested that the standing crop estimates were one-third the 1948-1950 levels (McPeak 1980). The differences between these two surveys may be attributed partially to methodology, including sampling bias and the use of remote sampling gear. The distribution of standing crop and species composition relative to depth, substrate and wave exposure were not examined in these earlier studies. Population structure and plant morphology data were also excluded.

Advances in both remote sensing and diving technologies were used to update and more accurately define the subtidal Laminaria resource in southwestern Nova Scotia.

The purpose of this project was to define the extent, amount, and character of the kelp resource within a 7 by 3 nautical mile section of the southwestern Nova Scotia coast. A renewed interest in the exploitation of Laminaria resources required updating and upgrading of earlier surveys to enable development of management strategies, estimates of sustainable yield and harvesting impact. We also evaluated the cost effectiveness of the methods in regard to their application to the entire coastline (Sharp et al. 1980).

2.0 MATERIALS AND METHODS

2.1 THE STUDY AREA

A section of the coastline adjacent to the only Canadian alginate processing facility (Scotia Marine Products Ltd., Woods Harbour, N.S.) was chosen as the most probable site for future resource utilization (Fig. 1). The area includes a low-lying group of islands and a portion of the mainland.

The primary substrate of the intertidal and shallow subtidal zone is granitic boulders. Sand and gravel dominate in areas deeper than 10 m. The area has a tidal range of 5.0 m, which generates high-velocity (maximum 10 km h^{-1}) tidal currents around shoals and islands. Water depth in the survey area averages 4.0 m (below chart datum). The maximum survey depth was 16 m. The slope of the shore ranges from 1:25 to 1:100, and there are extensive shoals.

The western shores of the islands in this area have an open angle of 180° exposed to wave action (in most cases with an unlimited fetch) (Fig. 1). The eastern sides are sheltered by the mainland less than 3 km away. Prevailing winds are from the south and southwest in summer. In the winter, the winds are from the northwest, north, and west. The area is ice-free in the winter, except at the heads of inlets. Surface-water temperatures range from a minimum of -1° to $+1^\circ\text{C}$ in winter to a maximum of 14° to 16°C in late summer.

The zonation of macroalgae is very uniform when suitable substrate is available. The upper intertidal zone is fringed by Fucus vesiculosus. Below, a wide band of Ascophyllum nodosum Linn. extends from +3 m to 0 m chart datum. Chondrus crispus Stackhouse is an understory of A. nodosum to +1 m but reaches maximum coverage between chart datum and -3 m. Laminaria digitata and L. longicruris occasionally occur above chart datum, but maximum cover is between chart datum and -5 m, overlapping C. crispus distribution (Pringle and Semple 1980).

2.2 AERIAL PHOTOGRAPHY

Kodak Aerocolor 23 cm x 23 cm film format was recommended as a water penetrating film by the Canada Centre for Remote Sensing (Anon. 1977; Haegele 1978). A Wild RC-8 camera with a 152.44 mm lens and Anti Vignette Filter was mounted in a Beach 18 CF-LWC airplane. The survey was flown at an altitude of 1,500 m providing a 1:10,000 photo scale with 80% forward over-

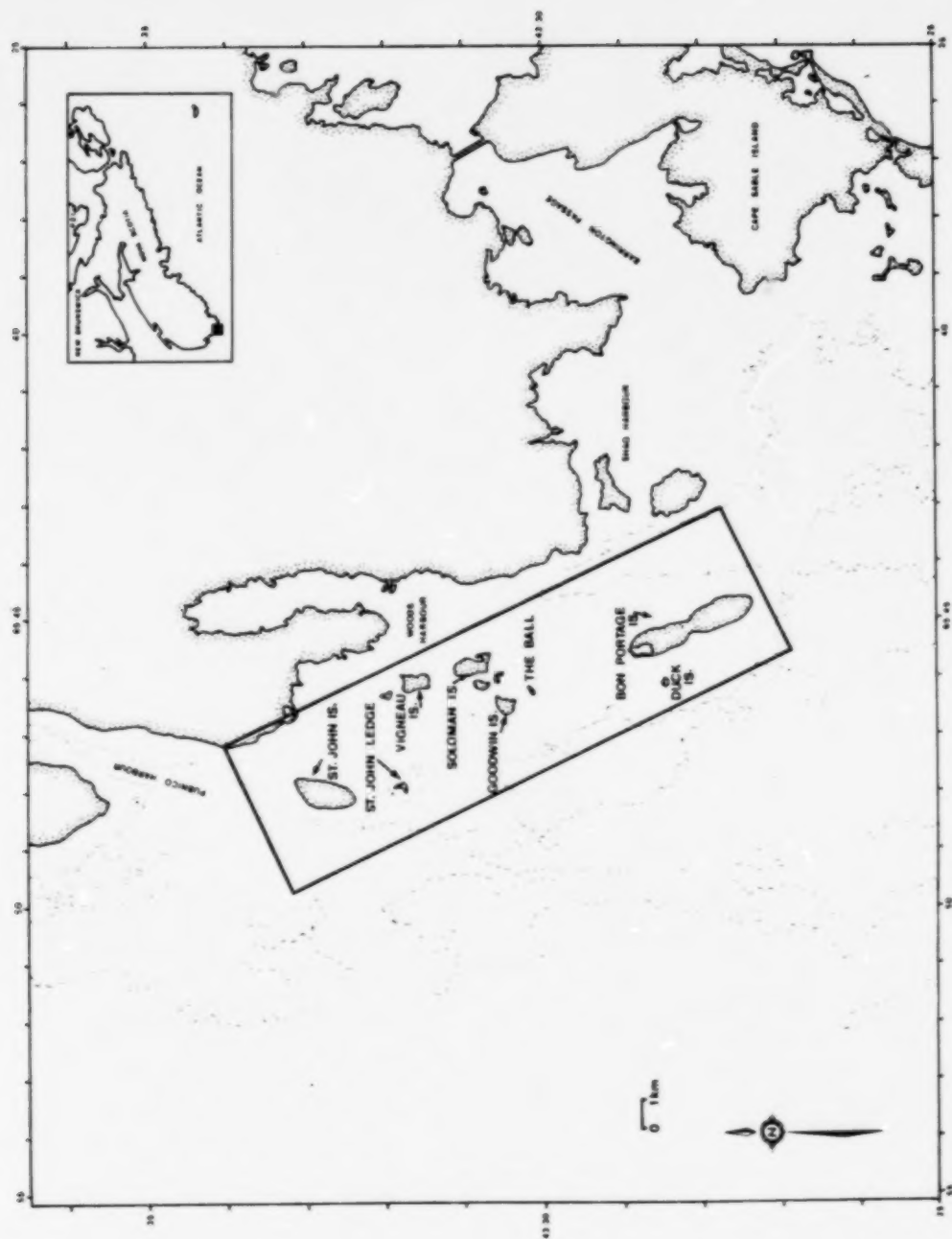


Figure 1. The area surveyed by aerial photography and sampled by diving for *Laminaria* spp. in southwestern Nova Scotia. Insert: Nova Scotia and the location of the study area.

lap and 20% sidelap. The flight occurred on July 10, 1980, between 14:00 and 15:00 h AST, at a tide height of 0.6 m with a northwesterly wind of 5-9 km h⁻¹ and clear skies over the flight lines. Required minimum conditions of 1 m tide level, 35° sun angle, and less than 10 km h⁻¹ wind velocity were met.

The best resolution of subtidal algae on individual diapositives was obtained by 0.5 F-stop overexposure. Diapositives were examined in stereo pairs under a Jena Interprescope 2C enabling 15 x enlargement when definition of species was not distinct. Sample photos were examined by a phycologist and a technician with air photo interpretation skills. The limits of each zone were drawn on acetate sheets from stereo pairs with minimal surface glare. The areas of species zones were determined by planimetry. The colour ranges used for identifying the species groups were as follows:

- a. Fucoids, principally A. nodosum: brownish yellow to light brown;
- b. Chondrus and Laminaria-Chondrus associations: purple to reddish brown, with a mottled texture;
- c. Laminaria (submerged): blue to black, with occasional parallel orientation of clumps;
- d. Eelgrass (Zostera marina): dark green with off-white or grey background in sheltered areas.

2.3 GROUNDTRUTHING

A diving survey was necessary to groundtruth the accuracy of air photo interpretation and to estimate kelp biomass. Groundtruthing was conducted from July 9 to August 10, 1980, by five SCUBA divers using 5 m boats. Observations from a 300 m altitude overflight on July 8 were used to position 44 transects. Transects were located only in kelp beds observed in the overflight, thereby being biased rather than random, to allow comparison with kelp bed limits defined in the aerial survey. Triangulation with compass bearings to navigational aids fixed the origins of transects for mapping purposes.

On continuous shorelines, transects were placed 200 m apart. The inner edge of kelp distribution was located by a diver and buoyed. The diver was towed on a sled to the outer bed edge and the location was marked. The team returned to the shore end and a weighted 200 m line (marked at 5 m intervals) was laid from the boat along a compass bearing originating at the inshore buoy. A minimum of five station locations were marked by buoys at equal distances to the end of the transect.

The wave exposure of each transect was determined using the following index:

<u>Index</u>	<u>Description</u>
1- Very Sheltered	A fetch ≤ 1 naut. mi. in other than a southerly direction (prevailing direction of winds spring - fall).
2- Sheltered	An open angle $\leq 10^\circ$ with unlimited fetch or any angle fetch > 1 naut. mi. in a southerly direction.
3- Semi-Sheltered	Open angle with unlimited fetch open to a southerly direction 10° to 25° .
4- Semi-Exposed	Open angle of 25° to 50° with unlimited fetch.
5- Exposed	Open angle $> 50^\circ$ with an unlimited fetch open to a southerly direction.
6- Very Exposed	Open angle $> 70^\circ$.

A diver swam the complete length of the transect, marking observations on distance to and depth of changes in kelp distribution, substrate type, and understory. Substrate was characterized as one or a combination of the following categories:

<u>Category</u>	<u>Description</u>
1	Bedrock of low relief (< 0.5 m change in height).
2	Boulders tightly packed (no secondary substrate visible).
3	Boulders loosely packed (patches of substrate < 0.5 m between boulders).
4	Scattered boulders (more than 0.5 m between).
5	Cobble (rocks less than 0.2 m diameter).
6	Gravel.
7	Sand.

Relative abundance of kelp species >20 cm in length was recorded in four categories: absent; present in small numbers; common ($>3 \text{ m}^{-2}$); and abundant ($>10 \text{ m}^{-2}$).

Following the general survey of the transect, five buoyed stations equidistant along each transect were sampled. At each station divers recorded the time, depth, substrate type, percentage cover of the understory and, within two 1 m^2 open-ended metal quadrats, the number of plants of each kelp species greater than and less than one metre in length. All kelp plants within a third quadrat were collected for measurements of stipe length, blade length, blade width and total wet weight.

2.4 ANALYSIS

A total of 651 quadrats were sampled at 217 stations and 2,641 plants were measured. Plant density, biomass, and size frequency data from all 44 transects were used for statistical analysis (correlation tests and Student-Newman-Keuls significance tests) to establish the variation of the kelp features with depth, wave exposure, and substrate type.

The calculation of total kelp standing crop in the study area was based upon two assumptions. The best average biomass per square meter for a shoal or island area was the composite mean of all samples taken from that area. Secondly, the total area of kelp was equal to the sum of all areas identified as having kelp cover in the photo interpretation, plus the area determined by the diving survey. To interpolate between transects, the area defined by groundtruthing was assumed to be inversely proportional to the distance from the shore (or start of a transect). Therefore, the area which could be added by interpolation between groundtruthing transects was triangular for each transect to the edge of the kelp bed identified by aerial survey or to adjacent transects $<500 \text{ m}$ apart at the seaward end [e.g. Transects 25 and 26 (Fig. 7)]. The width of the triangle base was determined by adjacent transects and/or aerial photography interpretation.

Analysis proceeded in two stages. The first was a comparison of mean density and biomass with groupings of depth, substrate, and wave exposure for all stations. Secondly, stations from specific geographic areas, differing primarily in one factor of wave exposure, substrate, or current speed were compared; e.g., St. John Ledge, a wave-exposed bed, versus Vigneau Island, which is semi-sheltered.

Population structure information was treated in two ways. Mean values for primary morphological measurements (stipe length, blade length and width, wet weight) were compared

between depths, substrates, and wave exposure. Log transformation normalized the L. longicruris data, but was not effective for L. digitata data. Mann-Whitney U Tests were used for non-normal data (Hull and Nie 1981). Linear correlations of blade length against stipe length were calculated for L. longicruris and L. digitata at sheltered and wave-exposed stations.

3.0 RESULTS

3.1 PHYSICAL CHARACTERISTICS OF THE GROUNDTRUTHING STATIONS

A total of 651 quadrats on 44 transects were documented. These observations provided a detailed description of the predominant physical characteristics of the kelp beds in the study area.

Seventy-five percent of the quadrats were at exposed and very exposed sites (Table 1). Very sheltered and semi-exposed shores were absent in our survey area. Boulder substrate was dominant in the quadrats (49.4%). Smaller, less stable substrates were more common below 5 m (all references to water depth relative to chart datum). Non-uniform (mixed) substrates occurred in 20.7 to 36.9% of the quadrats.

Ninety-five percent of the survey area was less than 9 m in depth and contained 1,331 ha less than 5.5 m deep. Depths greater than 5 m were most common at wave-exposed sites. Biomass samples from 0 to 5 m depth comprised 67% of all samples.

3.2 KELP BIOMASS AND DENSITY: RELATIONSHIP TO PRIMARY PHYSICAL GRADIENTS

3.2.1 Water Depth

Biomass of both L. longicruris and L. digitata peaked significantly ($p \leq 0.05$) at 0-5 m, but there was no pronounced gradient of plant density related to depth (Table 2). Laminaria longicruris density tended to be greater at 0-5 m, but differences between depths were not significant except for the 10-15 m grouping. The density of L. digitata <1 m long was not significantly different over the whole depth range (Table 2). Large plants (>1 m long) were significantly more abundant at mid-depth than in shallower and deeper water (Table 2).

3.2.2 Substrate

Substrate size, type and distribution tended to affect plant biomass and density, but there were no significant gradients. Areas with cobble and gravel substrate tended to have

Table 1. Percentage distribution of biomass samples (n=217) in the kelp survey.

Depth (m)	Sheltered	Semi-Sheltered	Exposed	Very exposed	Total at depth
0	0.9	3.7	3.7	6.9	15.2
-1	0.5	4.1	5.5	2.8	12.9
-2	1.4	4.6	2.8	4.1	12.9
-3	0	2.8	2.8	2.8	8.4
-4	0.9	3.2	5.5	1.8	11.4
-5	0.9	0.9	1.4	3.2	6.5
-6	0	0.5	4.1	4.6	9.2
-7	0	0.5	3.2	2.3	6.0
-8	0	0	2.3	3.2	5.5
-9	0	0.5	0.9	0.9	2.3
-10	0	0	1.8	2.8	4.6
-11	0	0	0.9	0.9	1.8
-12	0	0	0.9	0.5	1.4
-13	0	0	0.9	0	0.9
-14	0	0	0.5	0	0.5
-16	0	0	0.5	0	0.5
Total	4.6	20.8	37.7	36.9	100.0

Table 2. Density and biomass of Laminaria longicruris (Ll) and Laminaria digitata (Ld): relationship with water depth (mean $\pm$ standard deviation).

Depth (m)	Plants <1 m long; no. m ⁻²		Plants >1 m long; no. m ⁻²		Biomass kg m ⁻²	
	Ll n=651	Ld	Ll n=651	Ld	Ll n=217	Ld
+0	2.1 $\pm$ 2.3	1.6 $\pm$ 1.7	2.8 $\pm$ 3.2	1.4 $\pm$ 2.7	0.9 $\pm$ 1.6	0.7 $\pm$ 1.2
0-5	2.4 $\pm$ 4.2	2.5 $\pm$ 2.3	4.7 $\pm$ 4.7	2.4 $\pm$ 2.2	3.5 $\pm$ 4.4	1.9 $\pm$ 2.5
5-10	1.3 $\pm$ 4.1	2.8 $\pm$ 2.1	1.8 $\pm$ 2.3	2.6 $\pm$ 1.9	1.2 $\pm$ 2.0	1.2 $\pm$ 0.9
10-15	0.5 $\pm$ 0.8	2.7 $\pm$ 3.4	0.6 $\pm$ 1.0	1.6 $\pm$ 1.4	0.3 $\pm$ 0.4	0.6 $\pm$ 0.7

higher densities of smaller (<1 m long) L. longicruris (Table 3). Larger plants (>1 m) occurred at higher densities on boulder substrate (Table 3). The biomass of L. longicruris was greatest on loosely packed boulders, but this biomass was only significantly different compared to the biomass of L. longicruris in sand dominated areas (Table 3).

The density of smaller L. digitata did not vary significantly within the range of substrate types. Plants over 1 m in length were most dense on boulder substrate (Table 3). L. digitata showed no significant variation in biomass related to substrate type.

3.2.3 Wave Exposure

Wave exposure had a reciprocal effect on L. longicruris and L. digitata abundance. The densities of both small and large L. longicruris plants were significantly greater in sheltered locations (Table 4). The biomass of L. longicruris was also highest in sheltered locations. The density of large L. digitata was significantly greater in exposed environments, but the density of smaller L. digitata plants was not correlated with exposure (Table 4). Biomass tended to be greater at the more exposed sites, but there were no significant differences between means ($p < 0.05$).

3.3 OTHER LAMINARIALES

Although this survey focused on Laminaria spp. data on three other kelp species were also collected. Mean biomass for these species was calculated only for those quadrats where they were present. Alaria esculenta (Linn.) occurred predominantly at shallow-water stations, averaging $0.2 \pm 0.6 \text{ kg m}^{-2}$. Maximum biomass was 1.9 kg m^{-2} on transect 44 at St. John Ledge. Saccorhiza dermatodea (De la Pylaie) J. Agardh had a similar distribution pattern, reaching 2.6 kg m^{-2} on transect 44, averaging $0.3 \pm 0.6 \text{ kg m}^{-2}$. Saccorhiza was restricted to sites with exposure to waves and/or strong currents (e.g., Lower Bar). Agarum cribrosum (Mertens) Bory was restricted to water depths exceeding 10 m. The highest biomasses were recorded off St. John Island and Goodwin Island (up to 0.4 kg m^{-2}); mean biomass was $0.1 \pm 0.1 \text{ kg m}^{-2}$.

3.4 PLANT MORPHOLOGY AND SIZE

3.4.1 Size Frequencies of the Total Population

Laminaria longicruris and Laminaria digitata populations in southwestern Nova Scotia have a significant proportion of young recruits present in the summer. Fifty percent of the

Table 3. Density and biomass of Laminaria longicruris (Ll) and Laminaria digitata (Ld): relationship with substrate (mean $\pm$ standard deviation).

Substrate ¹	Plants <1 m long; no. m ⁻²		Plants >1 m long; no. m ⁻²		Biomass kg m ⁻²	
	Ll	Ld	Ll	Ld	Ll	Ld
tight boulder	1.1 $\pm$ 1.6	2.3 $\pm$ 2.1	3.1 $\pm$ 3.1	2.5 $\pm$ 2.4	2.0 $\pm$ 3.2	1.5 $\pm$ 2.6
loose boulder	1.7 $\pm$ 2.8	2.5 $\pm$ 2.5	4.6 $\pm$ 5.2	2.5 $\pm$ 2.5	3.0 $\pm$ 4.3	1.6 $\pm$ 1.9
scattered boulder	1.9 $\pm$ 5.0	2.7 $\pm$ 1.7	3.0 $\pm$ 3.6	2.7 $\pm$ 1.9	1.9 $\pm$ 2.9	1.7 $\pm$ 2.3
cobble	2.8 $\pm$ 5.3	2.4 $\pm$ 2.0	3.0 $\pm$ 3.6	1.7 $\pm$ 1.6	2.1 $\pm$ 3.6	1.2 $\pm$ 1.3
gravel	3.5 $\pm$ 4.9	2.4 $\pm$ 1.8	2.0 $\pm$ 2.0	1.0 $\pm$ 1.2	1.9 $\pm$ 3.8	1.0 $\pm$ 1.1
sand	1.7 $\pm$ 2.1	2.2 $\pm$ 4.3	1.1 $\pm$ 1.1	1.0 $\pm$ 1.4	0.7 $\pm$ 0.8	0.8 $\pm$ 1.4

¹ Substrate type indicates the dominant classification, mixed substrate may be present.

Table 4. Density and biomass of Laminaria longicruris (Ll) and Laminaria digitata (Ld): relationship with exposure to waves (mean $\pm$ standard deviation).

Exposure Index	Plants <1 m long; no. m ⁻²		Plants >1 m long; no. m ⁻²		Biomass kg m ⁻²	
	Ll n=651	Ld	Ll n=651	Ld	Ll n=217	Ld
2 (sheltered)	4.6 $\pm$ 2.2	2.5 $\pm$ 1.8	9.6 $\pm$ 9.3	1.5 $\pm$ 1.2	5.0 $\pm$ 4.9	1.1 $\pm$ 1.3
3	1.8 $\pm$ 2.0	1.2 $\pm$ 1.6	3.8 $\pm$ 3.7	1.3 $\pm$ 2.5	2.7 $\pm$ 4.1	0.7 $\pm$ 1.1
5	1.3 $\pm$ 2.0	2.5 $\pm$ 1.9	3.6 $\pm$ 4.2	2.5 $\pm$ 1.8	2.6 $\pm$ 3.8	1.5 $\pm$ 1.5
6 (very exposed)	1.6 $\pm$ 4.4	3.0 $\pm$ 2.5	2.6 $\pm$ 3.9	2.7 $\pm$ 2.3	1.3 $\pm$ 2.4	1.9 $\pm$ 2.7

L. longicruris population in the study area was less than 229 cm in total length (Fig. 2A). The average plant weighed 382 g wet weight. Fronds weighing over 1 kg comprised only 1% of the population (Fig. 2B). The fiftieth percentile of blade width of L. longicruris was less than 20 cm; mean width was 20 cm (Fig. 2E). The maximum stipe length was over 3.2 m, but the mean was 60.0 cm (Fig. 2C). The blade length frequency was skewed to lengths less than 100 cm. The average blade length was 170 cm (Fig. 2D). The largest L. longicruris plant was 10.65 m long, weighing 2,300 g.

Laminaria digitata total frond length was more skewed to the lower size classes than L. longicruris (Fig. 3A). Mean frond length was 93 cm and the maximum length was 3.6 m. Stipes were predominantly (76%) less than 20 cm in length (Fig. 3C). Blade length of L. digitata was 75% of the total frond length. Therefore, the pattern of blade length distribution was very similar to that of total frond length (Figs. 3A,3D). Blade width was 25% of blade length, averaging 27.0 cm (Fig. 3E). An average plant weighed 256 g, and 53.7% of the L. digitata plants were less than 125 g in weight (Fig. 3B).

3.4.2 Laminaria longicruris Size Frequencies and Environmental Variables

Members of the Laminariales exhibit different recruitment patterns and different plant morphology within the environmental gradients of southwestern Nova Scotia. The mean total length, stipe length, blade length and width of L. longicruris plants >1 m below chart datum were significantly greater than the same morphological features of L. longicruris plants in shallower water (Table 5). Deeper plants were 1.6 times heavier, on average, than shallower plants.

Comparisons were made of pooled samples from predominantly exposed transects (St. John Ledge) with those from the sheltered east side of Bon Portage Island (Fig. 1). Sheltered plants were significantly longer (1.9x), heavier (1.7x), and wider (2.0x) than those at exposed sites (Table 6). The ratio of stipe length to blade length was significantly greater in the sheltered population; 0.3 compared to 0.2 (Fig. 4A). Similarly, the ratio of blade width to blade length in the sheltered population was greater (0.12) than at exposed locations (0.10).

Laminaria longicruris from the sheltered sites showed 2 modes of total plant length; 320 cm and 40 cm (Fig. 5). Although there were plants over 500 cm in total length at exposed sites, the 0 to 40 cm size class comprised approximately 50% of all the L. longicruris plants measured (Fig. 5).

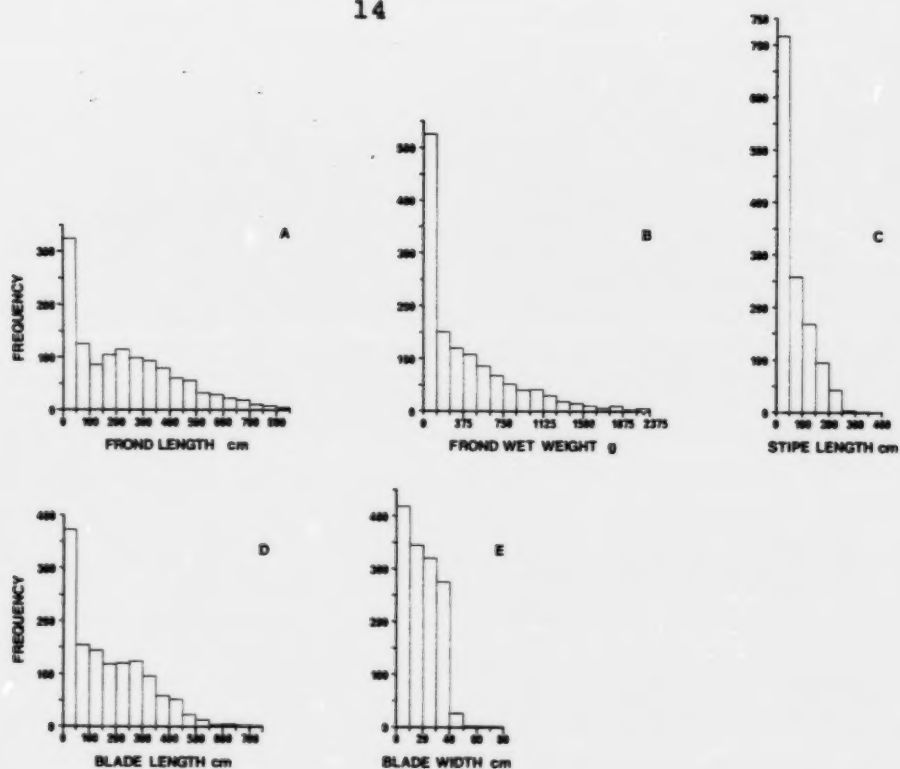


Figure 2, A-E. The size distribution of major morphological measurements for all *Laminaria longicruris* sampled in July and August, southwestern Nova Scotia.

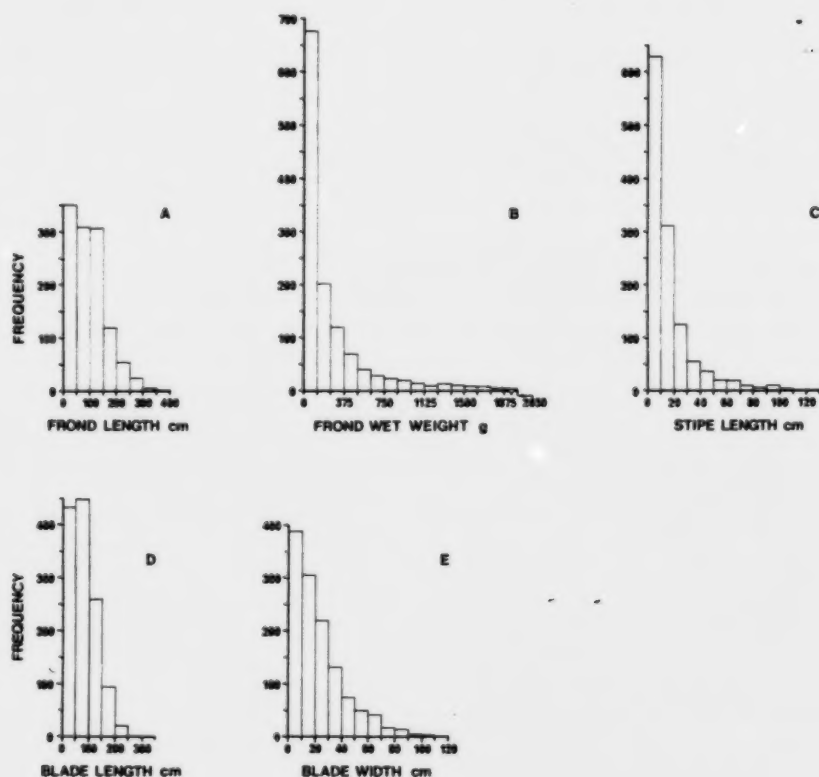


Figure 3, A-E. The size distribution of major morphological measurements for all *Laminaria digitata* sampled in July and August, southwestern Nova Scotia.

Table 5. Morphological features of Laminaria longicruris (mean $\pm$ standard deviation); relationship with water depth¹.

	Stipe length (cm)	Blade length (cm)	Blade width (cm)	Total length (cm)	Total weight (g)
Shallow (<1 m below datum)	44.2 ± 41.3 max. 201.0 n = 380	142.7 ± 115.9 max. 485.0 n = 391	15.4 ± 10.5 max. 71.0 n = 391	186.8 ± 148.3 max. 686.0 n = 384	272.4 ± 299.5 max. 1,415.7 n = 391
Deep (>1 m below datum)	66.7 ± 67.5 max. 317.0 n = 899	181.7 ± 156.1 max. 859.0 n = 901	18.4 ± 12.5 max. 70.0 n = 901	247.3 ± 214.3 max. 1,065.0 n = 897	429.0 ± 488.6 max. 2,654.0 n = 904

¹ All differences between the morphological features of shallow and deep populations are significant ($p \leq 0.05$).

Table 6. Morphological features of Laminaria longicruris at selected exposed and sheltered sites (mean $\pm$ standard deviation).¹

	<u>Exposed</u> (St. John Ledge)	<u>Sheltered</u> (east side of Bon Portage Island)
Stipe Length (cm)	<u>24.4$\pm$44.4</u> max. 237.0 n = 165	<u>49.6$\pm$37.6</u> max. 174.0 n = 232
Blade Length (cm)	<u>99.1$\pm$146.2</u> max. 656.0 n = 169	<u>185.8$\pm$109.8</u> max. 446.0 n = 239
Blade Width (cm)	<u>9.8$\pm$12.6</u> max. 71.0 n = 169	<u>18.1$\pm$8.6</u> max. 41.0 n = 239
Total Length (cm)	<u>123.3$\pm$186.8</u> max. 848.0 n = 168	<u>237.4$\pm$134.4</u> max. 578.0 n = 232
Total Weight (g)	<u>194.5$\pm$436.1</u> max. 2,061.0 n = 169	<u>329.9$\pm$259.7</u> max. 1,238.5 n = 240

¹ All differences between the morphological features of exposed and sheltered populations are significant ($p \leq 0.05$).

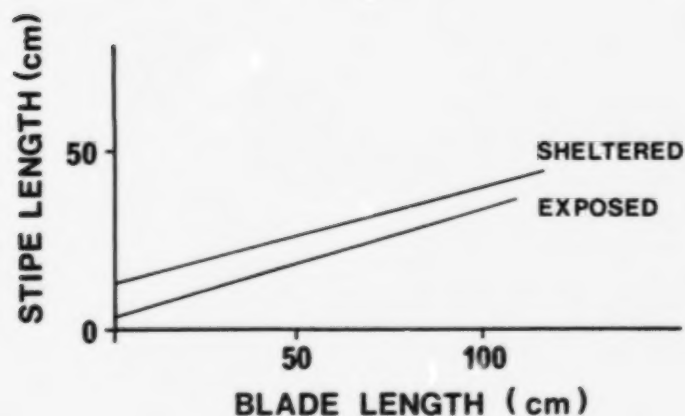


Figure 4A. The relationship between stipe length and blade length in Laminaria longicruris populations from sheltered and wave-exposed locations in southwestern Nova Scotia, July and August.

$$\begin{aligned}\text{Sheltered: } y &= 13 + .24x \quad r = .61 \\ \text{Exposed: } y &= 2.1 + .36x \quad r = .84\end{aligned}$$

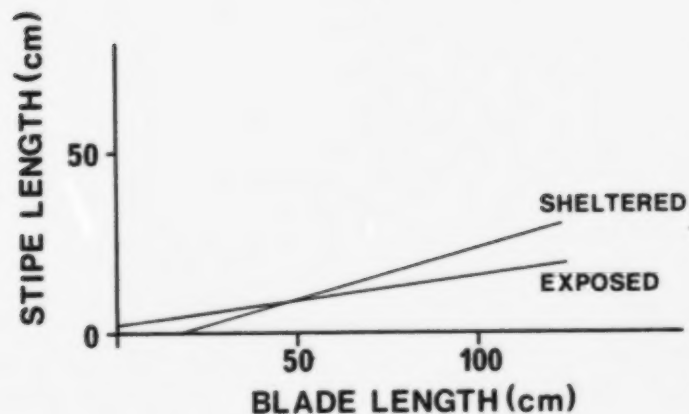


Figure 4B. The relationship between stipe length and blade length in Laminaria digitata populations from sheltered and wave-exposed locations in southwestern Nova Scotia, July and August.

$$\begin{aligned}\text{Sheltered: } y &= 2.8 + .15x \quad r = .66 \\ \text{Exposed: } y &= -2.9 + .24x \quad r = .60\end{aligned}$$

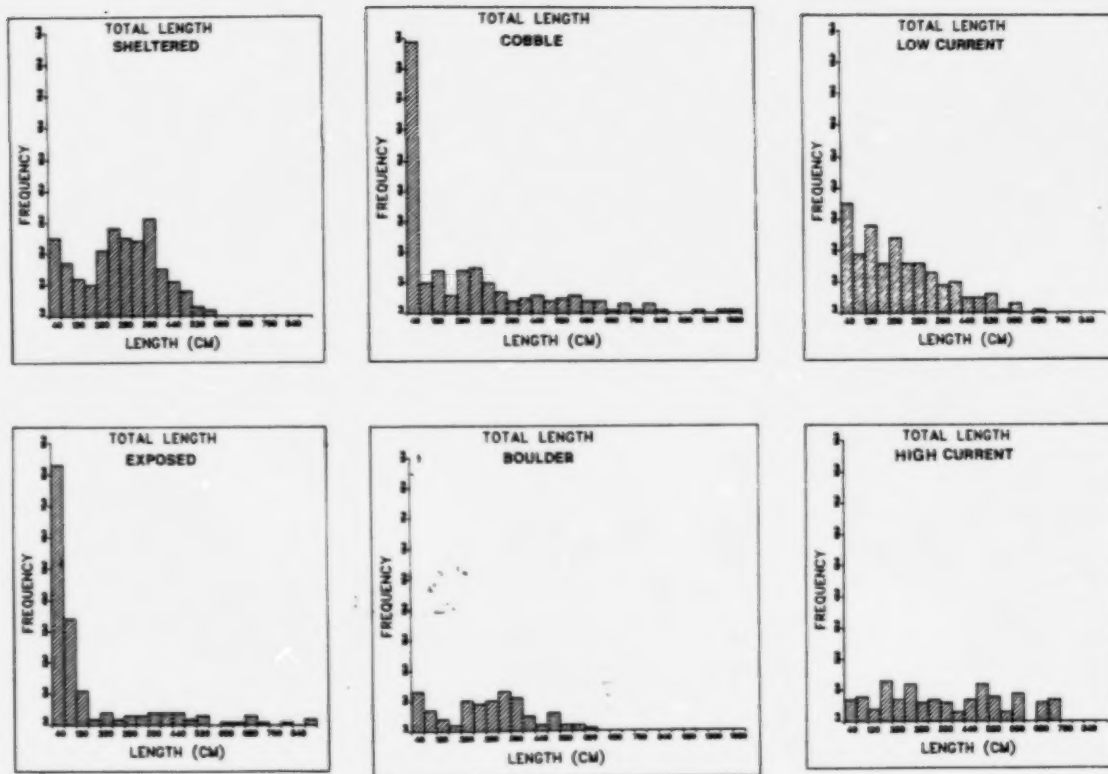


Figure 5. Distribution of total frond lengths of *Laminaria longicruris* at two extremes of wave exposure, substrate type, and current speed.

Although it was difficult to select stations where substrate type was independent of exposure or water depth, we compared L. longicruris plants on four transects with predominantly boulder substrate with those from three transects with predominantly cobble substrate (Table 7). Although there were some significant differences (particularly in blade length and total length), these were not sufficient to isolate a substrate effect. Size frequency histograms show few small (0 to 40 cm class) plants on boulder material (Fig. 5).

The largest L. longicruris plants were found in areas of strong tidal currents (e.g., Ball Bar). Average plant size was significantly larger on Ball Bar than in weak current areas (Table 8). Size frequency histograms indicate that large plants do occur in areas of low velocity currents (Fig. 5). The lower mean plant size at these sites is due to a high frequency of small plants (0 to 40 cm size class). Blades were wider per unit length in weak current areas (0.16) compared to those at strong current sites (0.10).

3.4.3 Laminaria digitata Size Frequencies and Environmental Variables

Laminaria digitata plants from shallow areas were not significantly different in morphology from plants collected in deeper water (Table 9). Plants from sheltered sites were significantly shorter than those from exposed sites (Table 10). Blades were narrower per unit blade length at exposed sites compared to L. digitata plants from sheltered sites (Table 10). Mean plant weight was 1.6 times greater at exposed sites compared to sheltered sites. The size frequency distribution of total lengths for L. digitata was similar at both exposed and sheltered sites, although the mode was slightly lower at the sheltered sites (Fig. 6). Stipes of plants over 50 cm long were longer per unit blade length in sheltered versus exposed locations (Fig. 4B).

Boulder substrate supported L. digitata plants with a larger mean size than those on cobble (Table 11). Plants in the 0 to 60 cm total length class were predominant at cobble sites (Fig. 6).

Areas with strong tidal currents supported populations of L. digitata with narrower blades per unit length (0.26) compared to plants in more quiescent areas (0.34) (Table 12). Overall plant length was only marginally (20%) larger in strong current areas and there was no significant difference in plant weight between strong and weak current areas. The frequency of length distributions for L. digitata from both strong and weak current areas were similar except in the larger size classes (Fig. 6).

Table 7. Morphological features of Laminaria longicruris at selected sites with different substrate (mean $\pm$ standard deviation).

	Boulder substrate		Cobble substrate
Stipe Length (cm)	$\frac{49.2 \pm 40.3}{\text{max. } 174.0}$ n = 98		$\frac{51.0 \pm 66.5}{\text{max. } 272.0}$ n = 214
Blade Length (cm)	$\frac{193.8 \pm 120.4}{\text{max. } 434.0}$ n = 97	— ¹	$\frac{143.1 \pm 173.4}{\text{max. } 859.0}$ n = 214
Blade Width (cm)	$\frac{15.9 \pm 8.7}{\text{max. } 38.0}$ n = 97		$\frac{14.4 \pm 13.3}{\text{max. } 46.0}$ n = 215
Total Length (cm)	$\frac{241.2 \pm 146.2}{\text{max. } 578.0}$ n = 97	—	$\frac{195.2 \pm 234.5}{\text{max. } 1,065.0}$ n = 215
Total Weight (g)	$\frac{368.3 \pm 312.0}{\text{max. } 1,238.5}$ n = 98	—	$\frac{338.9 \pm 529.4}{\text{max. } 2,437.0}$ n = 215

1 — indicates significant difference.

Table 8. Morphological features of Laminaria longicruris at selected sites with different current regimes (mean $\pm$ standard deviation).

	Strong Current (Ball Bar)		Weak Current (Vigneau Island)
Stipe Length (cm)	<u>89.2$\pm$ 73.4</u> max. 301.0 n = 145	— ¹	<u>48.9$\pm$ 41.6</u> max. 202.0 n = 206
Blade Length (cm)	<u>217.8$\pm$140.5</u> max. 516.0 n = 144	—	<u>144.8$\pm$113.7</u> max. 524.0 n = 207
Blade Width (cm)	<u>21.5$\pm$ 10.5</u> max. 53.0 n = 144		<u>21.1$\pm$ 11.8</u> max. 50.0 n = 207
Total Length (cm)	<u>303.9$\pm$208.4</u> max. 720.0 n = 144	—	<u>193.4$\pm$147.4</u> max. 647.0 n = 207
Total Weight (g)	<u>532.8$\pm$341.5</u> max. 1,951.9 n = 145	—	<u>310.2$\pm$336.3</u> max. 1,841.0 n = 207

1 — indicates significant difference ($p \leq 0.05$).

Table 9. Morphological features of Laminaria digitata
(mean $\pm$ standard deviation); relationship with water depth.

	Shallow (<1 m below datum)	Deep (>1 m below datum)
Stipe Length (cm)	$\frac{16.7 \pm 20.7}{\text{max. } 130.0}$ n = 245	$\frac{15.7 \pm 17.6}{\text{max. } 100.0}$ n = 975
Blade Length (cm)	$\frac{73.2 \pm 47.2}{\text{max. } 178.0}$ n = 252	$\frac{78.5 \pm 50.7}{\text{max. } 315.0}$ n = 995
Blade Width (cm)	$\frac{24.4 \pm 21.8}{\text{max. } 100.5}$ n = 252	$\frac{23.2 \pm 19.5}{\text{max. } 115.0}$ n = 995
Total Length (cm)	$\frac{91.2 \pm 63.9}{\text{max. } 308.0}$ n = 245	$\frac{93.4 \pm 64.7}{\text{max. } 365.0}$ n = 975
Total Weight (g)	$\frac{293.3 \pm 482.3}{\text{max. } 2,630.0}$ n = 251	$\frac{245.9 \pm 357.6}{\text{max. } 2,509.0}$ n = 995

Table 10. Morphological features of Laminaria digitata at selected exposed and sheltered sites (mean $\pm$ standard deviation).

	<u>Exposed</u> (St. John Ledge)		<u>Sheltered</u> (east side of Bon Portage Island)
Stipe Length (cm)	<u>23.4$\pm$ 27.0</u> max. 130.0 n = 156	— ¹	<u>12.1$\pm$ 9.0</u> max. 42.0 n = 54
Blade Length (cm)	<u>94.9$\pm$ 55.2</u> max. 315.0 n = 157	—	<u>80.0$\pm$ 45.9</u> max. 201.0 n = 54
Blade Width (cm)	<u>26.5$\pm$ 20.3</u> max. 100.5 n = 157		<u>25.1$\pm$ 19.9</u> max. 72.0 n = 54
Total Length (cm)	<u>119.1$\pm$ 75.2</u> max. 362.0 n = 156	—	<u>92.1$\pm$ 52.1</u> max. 230.0 n = 54
Total Weight (g)	<u>386.4$\pm$ 538.3</u> max. 2,630.5 n = 156	—	<u>246.1$\pm$ 371.0</u> max. 1,588.2 n = 54

1 — indicates significant difference ($p \leq 0.05$).

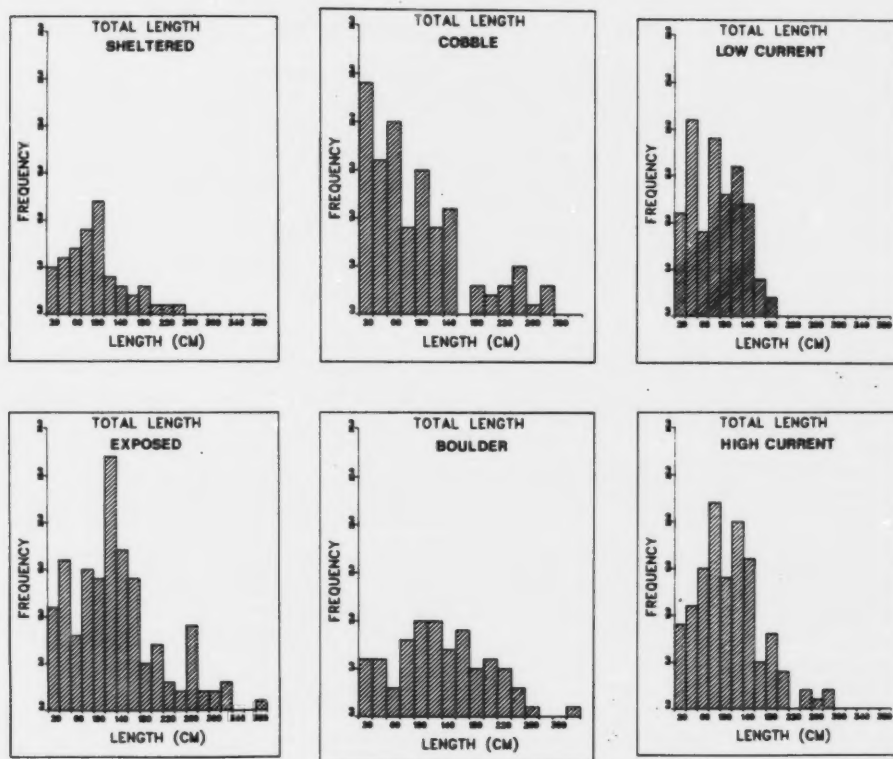


Figure 6. Distribution of total frond lengths of *Laminaria digitata* at two extremes of wave exposure, substrate type, and current speed.

Table 11. Morphological features of *Laminaria digitata* at selected sites with different substrate (mean $\pm$ standard deviation).¹

	Boulder substrate	Cobble substrate
Stipe Length (cm)	$\frac{19.7 \pm 17.7}{\text{max. } 91.0}$ n = 80	$\frac{14.9 \pm 16.8}{\text{max. } 81.0}$ n = 121
Blade Length (cm)	$\frac{99.4 \pm 67.1}{\text{max. } 214.0}$ n = 81	$\frac{67.1 \pm 55.0}{\text{max. } 220.0}$ n = 122
Blade Width (cm)	$\frac{31.9 \pm 22.2}{\text{max. } 99.0}$ n = 81	$\frac{21.1 \pm 21.8}{\text{max. } 115.0}$ n = 122
Total Length (cm)	$\frac{118.7 \pm 65.5}{\text{max. } 305.0}$ n = 80	$\frac{81.7 \pm 69.2}{\text{max. } 279.0}$ n = 121
Total Weight (g)	$\frac{377.5 \pm 413.4}{\text{max. } 1,719.0}$ n = 81	$\frac{225.6 \pm 371.6}{\text{max. } 2,509.0}$ n = 122

¹ All differences between the morphological features of the population on boulders compared to those of the population on cobble are significant ($p \leq 0.05$).

Table 12. Morphological features of Laminaria digitata at selected sites with different current regimes (mean $\pm$ standard deviation).

	Strong Current (Ball Bar)		Weak Current (Vigneau Island)
Stipe Length (cm)	$\frac{16.4 \pm 16.8}{\text{max. } 96.0}$ n = 155		$\frac{13.2 \pm 10.1}{\text{max. } 47.0}$ n = 107
Blade Length (cm)	$\frac{73.1 \pm 41.0}{\text{max. } 220.0}$ n = 165	— ¹	$\frac{62.4 \pm 35.4}{\text{max. } 144.0}$ n = 108
Blade Width (cm)	$\frac{22.7 \pm 18.4}{\text{max. } 93.0}$ n = 165		$\frac{27.7 \pm 23.7}{\text{max. } 91.0}$ n = 108
Total Length (cm)	$\frac{90.8 \pm 52.2}{\text{max. } 275.0}$ n = 155	—	$\frac{75.3 \pm 42.5}{\text{max. } 168.0}$ n = 107
Total Weight (g)	$\frac{212.9 \pm 334.6}{\text{max. } 2,355.0}$ n = 165		$\frac{237.5 \pm 318.4}{\text{max. } 1,541.1}$ n = 108

¹ — indicates significant difference ($p \leq 0.05$).

3.5 AERIAL PHOTOGRAPHY

The accuracy of air photo interpretation was dependent upon depth of penetration, adjacent substrate types and degree of intermixing between species. Throughout the survey area, Ascophyllum nodosum was emergent and easily distinguished from adjacent Chondrus crispus beds by colour on aerial photographs. There was overlap between the lower edge of C. crispus distribution and the upper limit of Laminaria spp. Plants were submerged or partially submerged below this transition zone. The lower edge of Laminaria spp. distribution was readily distinguished when the substrate changed abruptly within 5 m of chart datum. For example, on the east side of Bon Portage Island, boulder substrate terminates adjacent to a sand-dominated bottom (Fig. 7). Where there were no abrupt changes in bottom contrast, the characteristic blue-black colouration of kelp was muted and the outer boundaries were indistinct. Because of this problem, two categories of Laminaria cover were established for interpretation purposes: 1 - areas where the lower boundary of distribution was distinct or the characteristic colouration was unmuted were clearly Laminaria beds; 2 - areas where Laminaria could have caused changes in water colouration but without being clearly distinguished were labelled as speculated Laminaria.

The length of transects with Laminaria cover was determined by diving. The proportions of these lengths that could be determined by photographs was 41.8% (Table 13). Areas where the bottom sloped steeply to depths beyond 10 m (i.e. St. John Island - Fig. 8) had smaller portions of the resource revealed by aerial photography (Table 13). Areas with extensive shallow shoals (<3 m deep), such as Vigneau Island, were more effectively surveyed by photography (Fig. 9). Overall, 63% of the area of kelp cover was identified by aerial photography (Table 14).

3.6 STANDING CROP OF LAMINARIA SPP.

The groundtruthing observations and interpolation increased the area of kelp beds defined by photography by 59% (Table 14). The Bon Portage Island kelp bed was the largest defined area; 37.0% of the total kelp area (Fig. 7). This was followed by St. John Ledge and Ball Bar; 13% and 12%, respectively (Fig. 9 and 10).

Laminaria longicruris biomass was dominant in seven of the 11 survey areas (Table 14). It reached a peak biomass at Ram Island, but was most dominant on the lee side of Bon Portage Island (Fig. 7). Laminaria digitata predominated in the most wave-exposed areas such as St. John Ledge, Duck Island, and Goodwin Island (Fig. 9, 10, and 11).

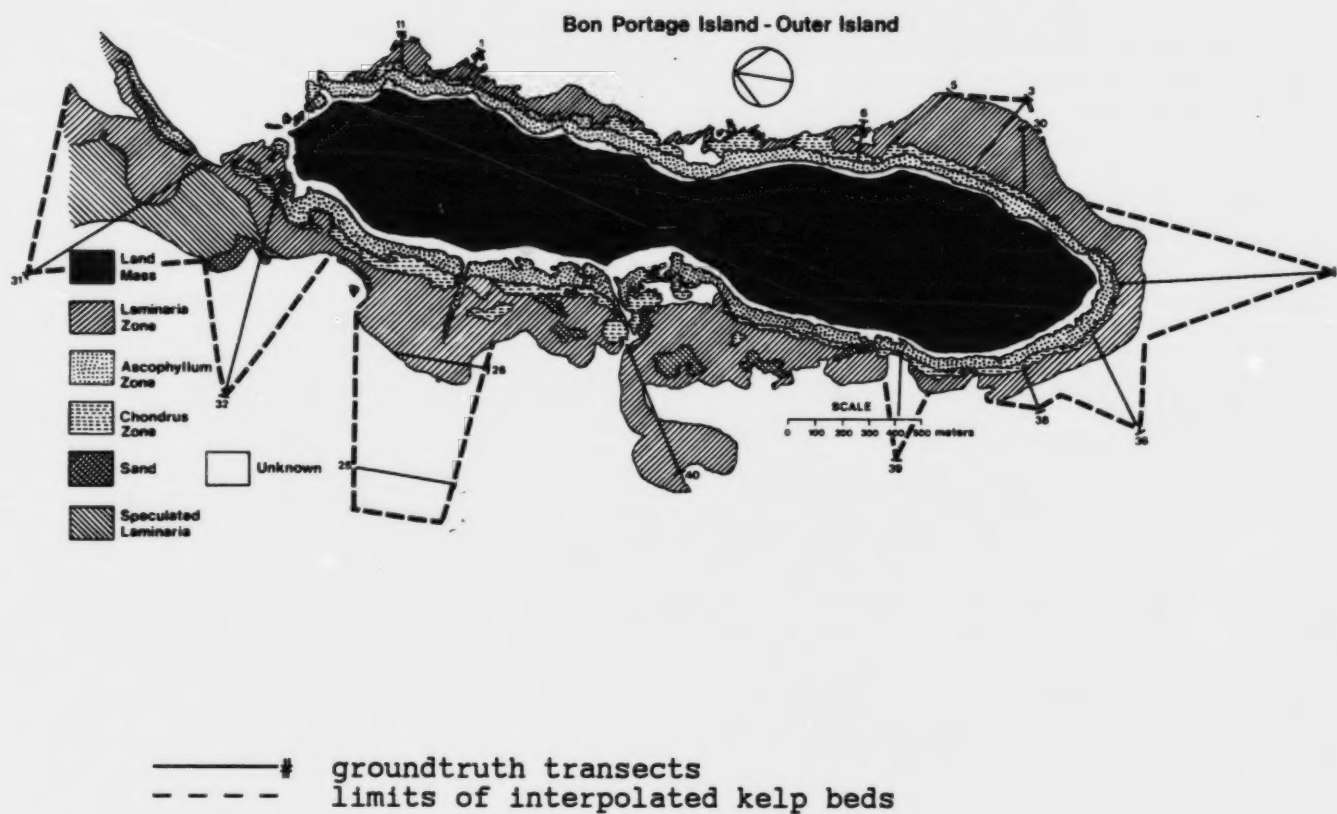


Figure 7. The distribution of benthic algae, Bon Portage Island, Yarmouth County, Nova Scotia.

Table 13. Proportion of transect length with Laminaria identified by aerial photography.

Area	Maximum	Minimum	Mean
St. John Island	.529	.190	.319
St. John Ledge	.734	.250	.487
Vigneau Island	1.000	.611	.851
Ram Island			.360 ¹
Goodwin Island			.340 ¹
Duck Island	.264	.125	.195
Ball and Ball Bar	.850	.096	.446
Bon Portage Island	1.000	.125	.349

¹ - 2 transects only.

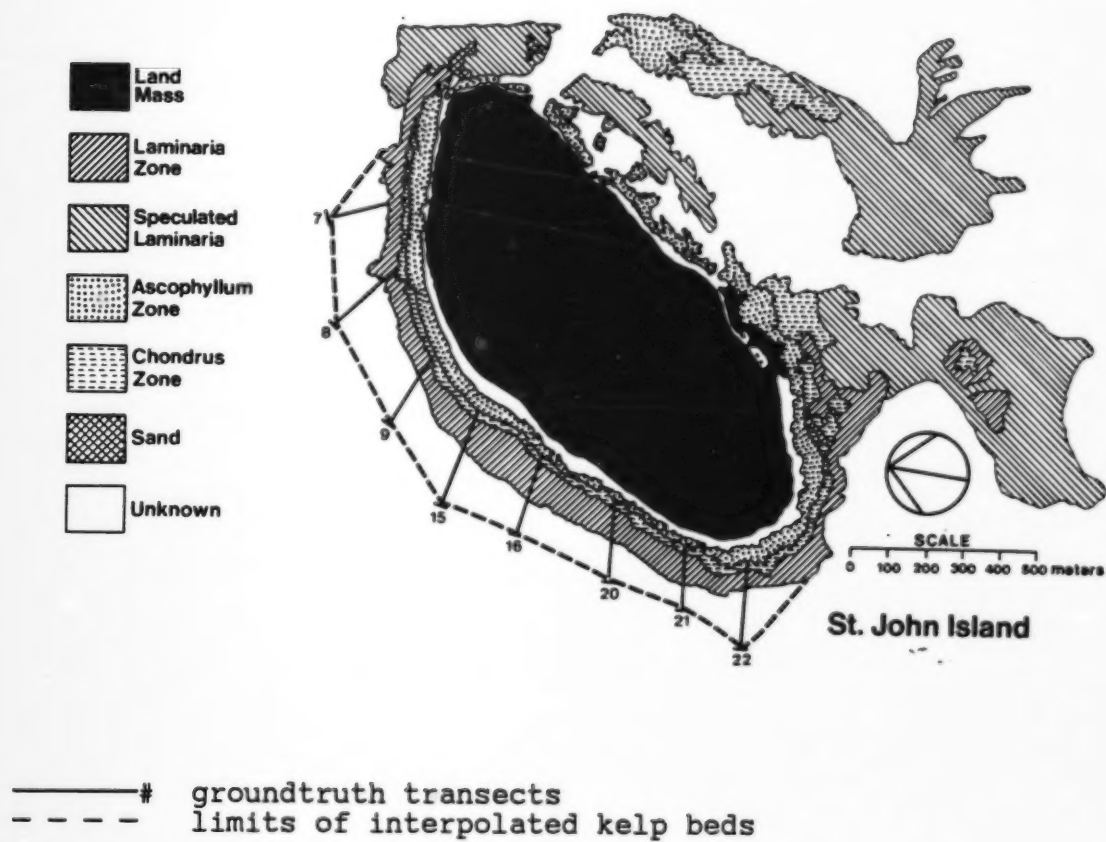


Figure 8. The distribution of benthic algae, St. John Island, Yarmouth County, Nova Scotia.

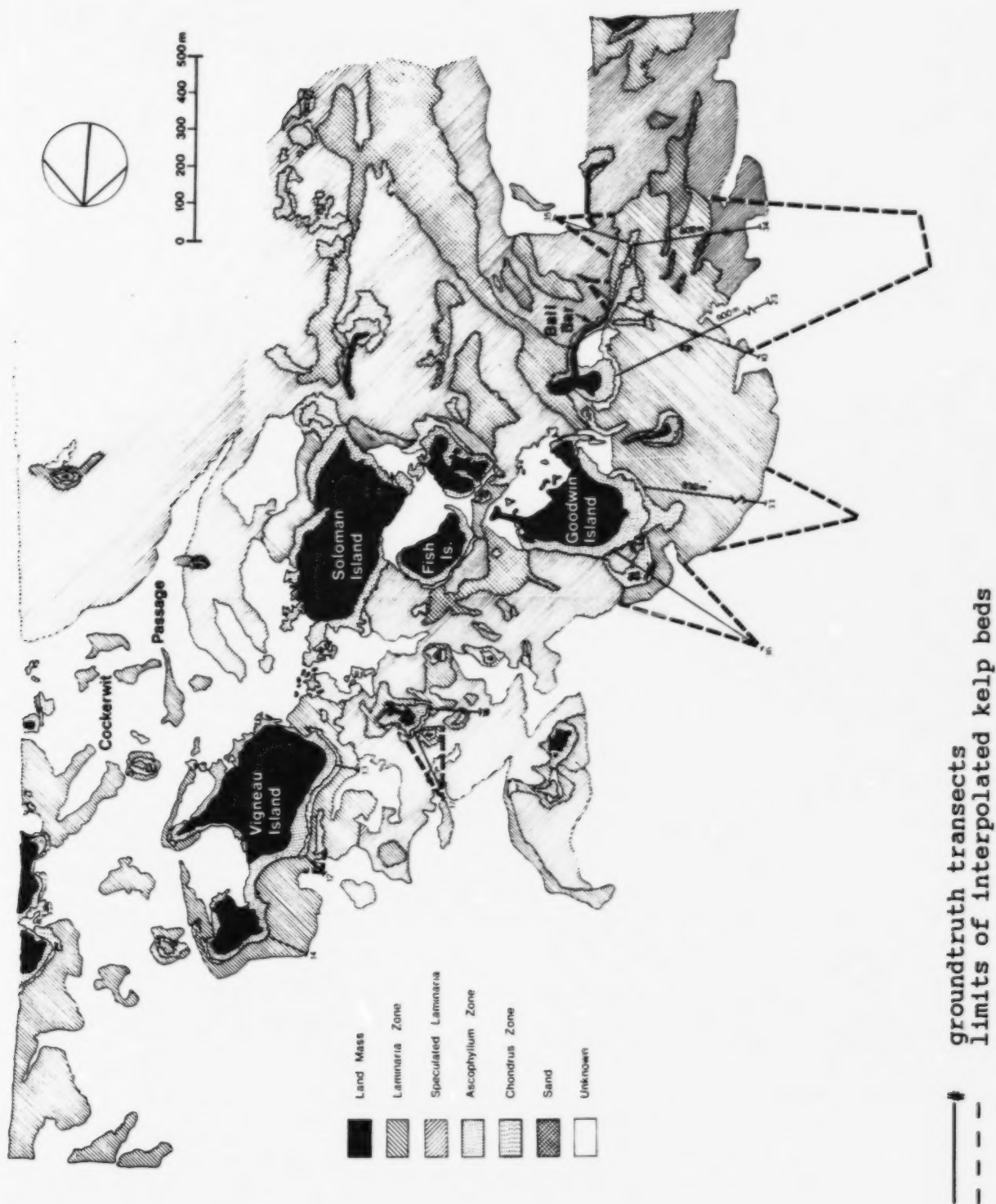


Figure 9. The distribution of benthic algae in an archipelago near Wood Harbour, Yarmouth County, Nova Scotia.

Table 14. Estimated standing crop (wet weight) of Laminaria longicruris (Ll) and Laminaria digitata (Ld) in the study area.

Location	Area of kelp defined by photography (ha)	Additional area defined by interpolation of groundtruthing data (ha)	Total defined kelp area (ha)	Percent defined by aerial survey	Average wet weight (g m ⁻²) of kelp (±S.D.)	Standing crop kelp (tonnes)	Biomass ratio Ll/Ld	Tonnes of kelp per ha	Total standing crop (both species) (tonnes)
					Ll	Ll	Ld		
St. John Ledge	35.8	40.0	75.8	47.0	1,604±2,097 (n = 25)	1,215.8	1,981.4	.6	42.1
St. John Island	19.6	21.0	40.6	46.2	859±1,449 (n = 40)	348.8	501.8	.7	20.9
Vigneau Island	37.0	0.1	37.1	100.0	2,817±5,061 (n = 15)	1,045.1	451.5	2.3	40.3
Ram Island	9.0	0.8	9.8	92.0	4,956±4,933 (n = 10)	485.7	112.3	4.3	61.0
Solomon and Raspberry	14.2	(no data)	14.2	-	2,817 -- (Vigneau Is. --- data)	400.0	172.8	2.3	40.3
Whale Island	9.4	(no data)	9.4	-	4,956 -- (Ram Is. data) - 1,146	465.9	107.7	4.3	61.0
Goodwin Island	55.5	11.0	66.5	83.0	1,167±2,278 (n = 10)	776.1	1,784.2	.4	36.5
The Ball and Ball Bar	53.6	17.9	71.5	74.9	3,416±3,671 (n = 22)	2,442.4	1,249.8	1.9	51.6
Duck Island	15.9	22.9	38.8	41.0	1,740±2,115 (n = 20)	675.1	836.9	.8	36.8
Bon Portage Island (lee)	29.8	2.0	31.8	94.0	2,653±3,611 (n = 30)	843.7	140.9	5.9	30.9
Bon Portage Island (exposed)	83.6	98.0	181.6	46.0	2,821±4,721 (n = 45)	5,122.9	2,215.5	2.3	40.4
TOTAL	363.4	213.7	577.1	-	-	13,821.5	9,554.8	-	23,376.3

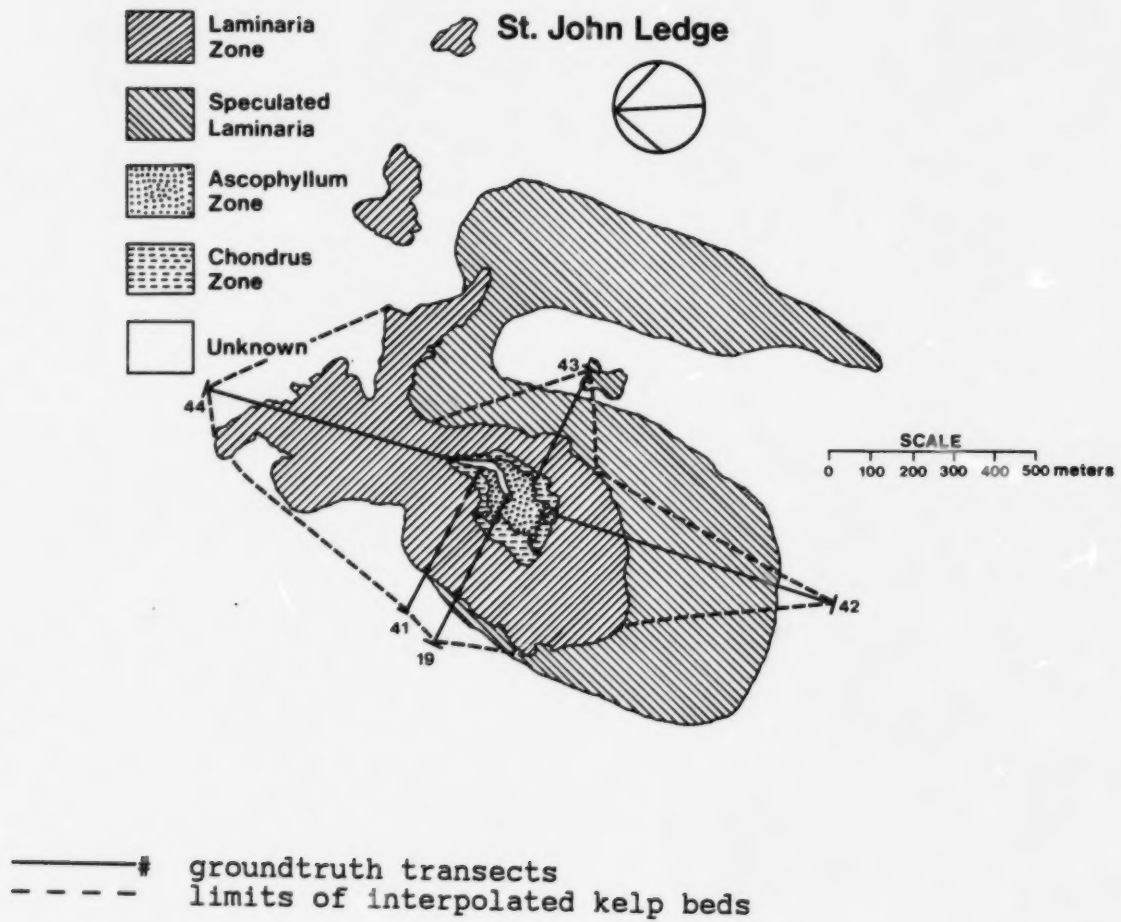


Figure 10. The distribution of benthic algae on St. John Ledge, Yarmouth County, Nova Scotia.

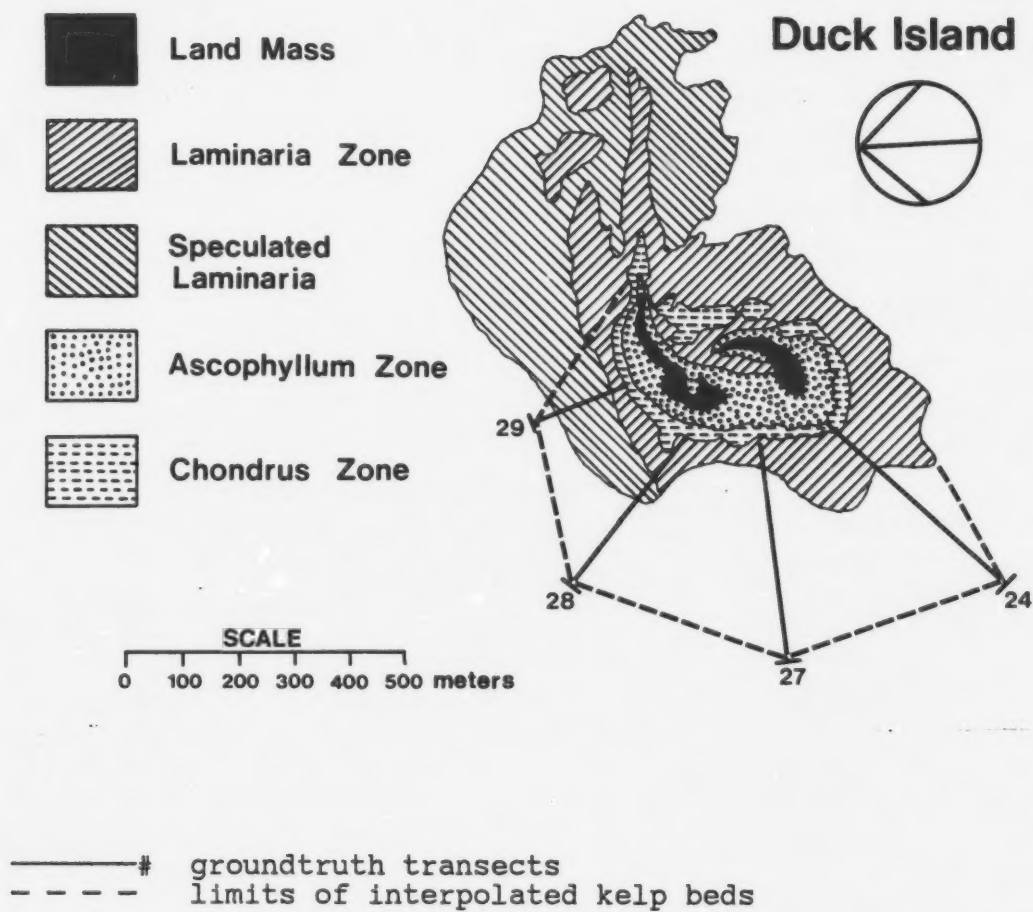


Figure 11. The distribution of benthic algae at Duck Island, Yarmouth County, Nova Scotia.

The total estimated standing crop of kelp in the study area was 23,376.3 t; 59.2% was L. longicruris. Three quarters of the standing crop was located in four of the 11 locations in the study area. The standing crop of kelp averaged 40.5 t ha⁻¹, ranging from 20.9 t ha⁻¹ at St. John Island to 61.0 t ha⁻¹ at Ram Island (Table 14).

4.0 DISCUSSION

The method used to calculate the total standing crop of kelp is conservative. We did not use the areas designated as speculated Laminaria (areas where kelp could have caused water colour changes but were not clearly distinguishable) in our calculations, except when they fell within the interpolated area around each groundtruth transect. The use of site specific values for calculation of biomass resulted in a lower total biomass than using overall average biomass per square meter values. Sampling 217 quadrats for biomass on 44 transects in a survey area of 577.1 ha compares favourably to sampling rates in surveys of kelp in other areas of the world (Table 15).

We compared mean biomass densities from our study with a number of Laminaria surveys throughout the world (Table 15). Mean values for L. hyperborea biomass densities generally exceed those reported for L. longicruris and L. digitata combined (Table 15). Laminaria longicruris and Laminaria digitata biomass densities reported in eastern Canada fall within the range of our study, with two exceptions. The studies of Mann (1972) in St. Margarets Bay and MacFarlane (1952) in southwestern Nova Scotia reported mean values near single maximum values found in our survey (Table 15). St. Margarets Bay kelp beds would be classified as sheltered to semi-exposed which may account for some high values; however, Gerard and Mann (1979) report mean values of 5.5 kg m⁻² in sheltered beds. MacFarlane (1952) used remotely operated grabs which over-sample, taking plants outside the quadrat area.

Several sites within southwestern Nova Scotia were the subject of resurvey allowing direct comparisons of total standing crop and distribution (Table 16). McPeak (1980) reported a mean value for 15, 1 m² quadrats on St. John Ledge of 5.88 kg m⁻². Our combined value (both L. longicruris and L. digitata) for 25 quadrats in this kelp bed was 4.2 ± 3.0 kg m⁻². Maximum biomass reached 12 to 18 kg m⁻² in some samples in our survey. Peak biomass at two sites in Lobster Bay occurred at the 3 m depth, within the 0-5 m range found in our survey (Smith 1985).

The area of kelp beds off southwestern Nova Scotia was estimated in several previous studies, including MacFarlane (1952), Wharton (1980), McPeak (1980), and Haggarty and Hillen-

Table 15. Comparisons of Laminariales surveys, level of sampling, and biomass estimates.

Location	Species	Season	No. of samples/size	Mean kg m ⁻² wet weight	Source
Kodiak Alaska	<u>L. dentigera</u> and other non-canopy keips	May	55/.25 m ²	2-35	Calvin & Ellis, 1978
Scotland	<u>L. hyperborea</u>	Dec.-Jan. Mar.-June	22/-	7.7-20.4	Jupp & Drew, 1974
Helgoland (North Sea)	<u>L. hyperborea</u>	Aug.-Nov.	61/1 m ²	0.1-11.1	Luning, 1969
Isle of Mann (Irish Sea)	<u>L. hyperborea</u>	June-July	80/1 m ²	.35-11.3	Kain, 1979
Southwest Cape Coast (South Africa)	<u>L. pallida</u> and <u>Ecklonia maxima</u>	—	120/2 m ²	.8-7.0	Field et al., 1980
Northwest Spain	<u>L. ochroleuca</u> and <u>Saccorhiza polyschides</u>	—	200/1 m ²	Lo - 0.03-2.3 Sp - 0.60-3.9	John, 1971
Grand Manan New Brunswick	<u>L. longicruris</u> (narrow and wide frond)	Summer	61/.85 m ²	5.5	Neish, 1973
Bay of Chaleur, Quebec	<u>L. longicruris</u>	—	132/1 m ²	.2-1.4	Gendron, 1983
St. Margarets Bay Nova Scotia	<u>L. longicruris</u> <u>L. digitata</u>	Summer	195/.25 m ²	16.0±2.2 SE 11.5±1.2	Mann, 1972
Southwestern Nova Scotia	<u>L. longicruris</u> <u>L. digitata</u>	Summer	- strips - grabs/.40 m ²	5.9-27.8	MacFarlane, 1952
Southwestern Nova Scotia	<u>L. longicruris</u> <u>L. digitata</u>	Summer	50/1 m ²	3.5-15.3	McPeak, 1980
Southwestern Nova Scotia	<u>L. longicruris</u> <u>L. digitata</u>	Summer	217/1 m ²	0.86-4.96 0.44-2.68	This Study, 1986
Southwestern Nova Scotia	<u>L. longicruris</u> <u>L. digitata</u>	Summer	40/.25 m ²	6.2 .7-1.8	Smith, 1985
Southern Nova Scotia	<u>L. longicruris</u>	Summer	-/.1 m ²	4.4-5.5	Gerard and Mann, 1979

Table 16. Historical comparisons of area and biomass of selected kelp beds, Southwestern Nova Scotia.

Study	Area comparison		Transect length (m) South Bon Portage Island
	St. John area ha	Ledge t ha ⁻¹	
MacFarlane, 1952	142	203	
McPeak, 1980	135	65	
This Study, 1986	76	42	1,000
Wharton, 1980	-	-	675
Haggarty and Hillenbrand, 1976	-	-	1,000

brand (1976). The St. John Ledge kelp bed surveyed by MacFarlane (1952) and McPeak (1980) was estimated at 1.9 and 1.8 times the area reported in this study (Table 16). In these earlier studies, the area of the kelp bed was estimated using depth contours and assuming continuous kelp cover within a contour. If the area designated as speculated kelp for St. John Ledge were included in our study the total area would be 115 ha. Our conservative assumptions using groundtruthing data may explain these differences in area estimates. The use of computer-aided selection of species colour, following the classification of grey tones, can eliminate most optic and planimetric errors in calculation of area (Sharp *et al.* unpublished data).

The majority of kelp biomass in southwestern Nova Scotia is in depths of 5 m or less. The penetration of aerial photography to 4.4 m delineates the majority of the high biomass zone. Groundtruthing transects enabled the confirmation of kelp in an additional 59% of the area defined by photography. The cost effectiveness of each survey method was examined by Sharp *et al.* (1981).

Laminaria longicruris blade linear growth peaks in the summer months at 1.4 to 1.5 cm day⁻¹, rapidly declining to 0.8 cm day⁻¹ in September (Gagné 1981). Blade erosion peaks in the summer and fall as does whole frond mortality of plants over 50 cm (Sharp, unpublished data; Smith 1985). These observations suggest that maximum biomass will occur in the early summer months (June-July) and begin to decline in subsequent months. At a 10 m depth station near the study area, L. longicruris density remained unchanged throughout the year, whereas L. digitata density declined in winter (Chapman, 1984). The lack of change in L. longicruris may be due to the inclusion of all recruits from earliest macroscopic stages. Blade growth and erosion of L. digitata followed a similar seasonal pattern to L. longicruris, with attrition occurring in the late summer and early fall (Smith 1985). The groundtruthing survey began on July 9 and ended August 10, prior to the period of maximum L. longicruris degradation and loss, near the anticipated standing crop peak.

Biomass variation with wave exposure, depth and substrate was observed, but was not useful as a basis for standing crop estimation, due to the multivariate interaction of these factors. Sampling bias was found when correlation between depth and average plant size was attempted, e.g., the deeper depths occurred at more wave exposed locations. Mean biomass within a depth or exposure range is useful in prediction of species composition and general gradients of biomass. Site specific biomass densities must be used to control the error of standing crop estimates. In areas where there are no abrupt changes in

environmental gradients, it has been proven feasible to use stratified values of biomass based upon depth (Gendron 1983).

The vulnerability of a kelp population to harvesting is related to the efficiency of harvesting equipment and the size distribution of plants. Size frequency distribution and individual frond biomass describe a population which has the majority of biomass at 1 m above the substrate contributed by 20% of the population. In wave-exposed areas or unstable cobble substrate, smaller plants predominate. Sheltered populations of L. longicruris were significantly less dense (8 m^{-2}) than at a nearby wave-exposed site (24 m^{-2}) (Gerard and Mann 1979). Due to a larger mean weight per plant, the biomasses at the two sites were similar: 4.4 kg m^{-2} (sheltered) versus 5.5 kg m^{-2} (exposed). The biomass difference in our study, between sheltered and exposed, was significant although it is possible that some substrate or depth effects related to exposure might affect our result. It is more likely that competition with L. digitata was the most important factor. L. digitata survives 1 to 2 yr longer than L. longicruris in southwestern Nova Scotia, providing it with a long-term competitive advantage, although probability of survival in the short term (1 yr) is less (Chapman 1984; Smith 1985). Mortality in L. longicruris is related to crowding and plant size, while L. digitata mortality is independent of these factors (Chapman 1984).

The polymorphism of L. longicruris between sheltered and exposed sites was consistent with earlier studies (Gerard and Mann 1979). Broad-bladed plants were typical of sheltered sites, but we also found that deeper plants showed some of the same morphology. Stipe length to blade length ratios of L. longicruris decrease with increasing wave exposure (Chapman 1973).

Kelp harvesting in southwestern Nova Scotia was a small industry between 1942 and 1949, reaching 3,000 t fresh weight annual landings (Sharp 1980). Preliminary assessments of biomass turnover and our detailed survey of approximately one tenth of the total shallow waters of southwestern Nova Scotia indicate that the potential for annual production is many times the historic harvest levels. As the demand for phycocolloids on the world market increases, the kelp resources of southwestern Nova Scotia will offer a significant opportunity for exploitation. This survey will provide the first step toward effective resource management strategies. Standing crop estimates combined with estimates of annual productivity form the basis for estimates of sustainable yield. Population structure and composition contribute to the determination of the harvestable biomass.

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